Animal and Machine Intelligence

Arrangements for week 1

Undergraduates

Introductory workshop on Monday 4th October 13:00-15:00 in PEV1 1A7

First lecture Tuesday 5th October 10:00 in PEV1 1A7

MSc. Students

First lecture Wednesday 6th October 12:00 in AS2

ANIMAL AND MACHINE INTELLIGENCE
Autumn 2004

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AIMS AND OBJECTIVES

The overall aim of this course is to develop your understanding of what it means for an animal or a machine to behave intelligently, and how brain and behavioural systems are adapted to enable an animal to cope effectively within its environment. You explore this topic in lectures and seminars through a number of case studies that are designed to acquaint you with recent behavioural and AI literature.

COURSE OUTLINE

Animals engage in a variety of complex behaviours that are intelligent in the sense of being well-adapted to particular situations. Thus, intelligence should perhaps not be thought of as a unitary phenomenon. Rather animals have multiple, specialised intelligences each of which is designed for particular tasks. Animals go in for computational economy and often do not build up detailed internal models of the world, using instead sensory information on-line to guide actions.

Developments in behavioural neuroscience and in artificial intelligence over the last decade have led to some convergence of the aims and methods of the two disciplines. In studies of behaviour, there is increasing acceptance of robot and computer modelling as experimental tools. In artificial intelligence and cognitive science, the focus has shifted from exploring high-level human intellectual capabilities toward detailed studies of the basic behaviours that are common to most animals, and that are required of autonomous robots. Our interdisciplinary course reflects this new movement and aims to show how the two fields can inform each other, to give an understanding of the subtleties of cognition in simple animals and the challenges faced by scientists trying to create artificial systems with the same behavioural capabilities as these animals.

We begin by discussing the evolution of views on animal intelligence and robot-building. The modern approach emphasises complete systems acting in the real world. This aims to avoid the pitfalls of earlier methods, even if it means confining ourselves to relatively simple systems Recent experiments are used to illustrate the developing methodology by which computer simulations and robotic experiments can stimulate biology (and vice-versa).

We will consider in detail several examples of ‘specialised or adaptive intelligences’ in invertebrates and vertebrates. The study of relatively simple animals (such as insects) turns out to be challenging rather than restrictive. Their capabilities often exceed what can be achieved in artificial systems or fully understood by biologists. We concentrate on navigation and foraging, and we will examine the behavioural and memory strategies that insects and other animals have evolved to accomplish these tasks.

Difficulties in controlling behaviour can be lessened by appropriate design of sense organs and effectors, and by exploiting properties of the environment in which the animal/machine operates. A telling example is the way in which the insect visual system has adapted to interpret the visual consequences of an animal’s own movements. We look at optic flow in insects and the specialised neural mechanisms that decode it.

The synaptic computations performed by real neurones in the insect visual system serve as an introduction to artificial neural networks (ANNs). ANNs are computer simulations or electronic circuits, at least partially based on observations of the structure and operation of animals' nervous systems. As we will see, they turn out to be very powerful computational devices for prediction, categorisation and learning and are becoming widely used in engineering and industry. They have also revolutionised our understanding of the brain in that appropriately configured and trained neural nets can in many cases substitute for explanations of behaviour that are cast in terms of rules and symbol manipulation.

We then consider what might be thought of as higher-level faculties and how they may have relatively simple antecedents, taking as an example the human ability to count and use number. This is put into a biological context by examining its possible origins in non-human animals and its neural basis.

Intelligence does not only exist at the individual level. Some tasks demand group co-ordination and intelligent algorithms can be implemented at the level of a group. Animals can obtain information and learn from observing and interacting with other members of a social group. Indeed one of the selection pressures driving the evolution of some high-level cognitive skills is thought to be a need to solve problems posed by social interactions. The course ends with a look at three aspects of social intelligence: i) the social organisation of foraging in bees; ii) culture and observational learning; iii) social intelligence and mind reading.

TEACHING METHODS

AMI is open both to final-year undergraduates and MSc students. Teaching is through lectures, seminars and an essay. All students should attend all lectures. However, there are separate seminars for undergraduate and postgraduate students. **Lectures** can only introduce a topic and you are expected to develop knowledge and analytical skills through reading critically the starred paper and a selection of the other recommended items. It is especially important that you integrate the different topics of the course. Again, lectures can only give pointers, developing a conceptual framework of your own is something that requires both individual thought and discussion with friends and colleagues. **Seminars** are an essential part of the course and may present material not covered in lectures. They are held primarily for group discussion of critical issues and for you to raise and discuss problems that you have with course material. We hope to organise one or two **workshops** during the course of the term. In these you will divide into groups and each consider a topic and report back to the class. The **essay** has both a learning and an assessment role. It should teach you to analyze a problem or present experimental material, in a logical, interesting and concise manner, if possible within an explicit conceptual framework. We urge you to write a detailed plan or outline of your essay before turning it into continuous prose and we are more than happy to provide feedback at that stage.

LECTURERS

Adrian Thompson, adrianth@sussex.ac.uk
Tom Collett, t.s.collett@sussex.ac.uk
Rob Harris, r.a.harris@sussex.ac.uk
Daniel Osorio, d.osorio@sussex.ac.uk

Ezequiel Di Paolo, ezequiel@cogs.sussex.ac.uk (advisor to MSc students)

Please do not hesitate to ask us if you have any questions!

LECTURES

Two per week, weeks 1 to 9: Monday at 14:00 Pevensey1 1A7 and Tuesday at 10:00 in Pevensey1 1A7.

SEMINARS

Undergraduates:

There are 8 seminars in the term beginning in week 2. **Seminar topics with suggested readings and questions for discussion are listed towards the end of the handout. Please come prepared having read and thought about the material!**

Group 1: Thursday 11:00 in MANT-3A18
Group 2: Thursday 14:00 in MANT-3A18
Group 3: Friday 16:00 in MANT-3A18

People will be put into groups in the 1st or 2nd lecture.

Postgraduates:

Seminars are weekly. They start in week 2. Contact Ezequiel Di Paolo for more details.

ASSESSMENT

Undergraduates

There will be an unseen exam that contributes to 85% of the marks awarded for the course, and one 3000 (+/- 20%) word assessed essay that contributes to the remaining 15% .

Essays

Essay submission
There is a strict deadline for submission. Essays must be handed in personally and a submission sheet signed on Thursday 13th January 2004 (Week 1 of the Spring Term) before 4.00 pm. Essays should be handed in either at the submissions desk in the foyer of the John Maynard Smith Bldg or at the Life Sciences School Office (JMS 3B10). There will be a notice on the day in the JMS Bldg telling you which location is correct. Coursework that is either early or late should be handed in directly to the School Office.

Please ensure that you have firmly attached a cover sheet to your coursework before you hand it in - these are available in advance from the Biology and Environmental Science Department Office. So that we can give you feedback on your essay, we would like you to put your name as well as your exam number on the essay.

If you must miss the deadline
Work can be handed in up to 24 hours after the deadline, but there will be a 10% deduction in the mark you receive. Work handed in later than 24 hours after the hand-in deadline will receive zero marks. If there is good reason why your work is handed in late, you should fill out an Impairment Form, which is available from the student coordinators in your School Office. You are advised to discuss what evidence (medical etc.) might be needed with them. The form together with any evidence should then be returned to the School office from where it is sent to the University Mitigating Evidence committee for decision.

Choosing your essay title
Sample essay titles are provided at the end of this handout. If you prefer, you may choose your own title, but it should be approved by one of the lecturers. We recommend strongly that you give a detailed plan of your essay to one of the lecturers well before the end of this term so that we have time to provide comments and advice before you write it in full.

Marking essays and feedback

Essays are double-marked and are retained in case the external examiner needs to see them in the summer. We will give you a grade and comments on your essay towards the end of the Spring term.

Postgraduates

Formal assessment is by submission of a short term paper (max. 3500 words) due by 12 noon on the first day of the Spring Term.

READING

There isn't a suitable textbook. Useful perspectives are to be found in D. McFarland and T. Bösser. *Intelligent behaviour in animals and robots* MIT Press; R. Pfeifer and C. Scheier, *Understanding intelligence*, MIT Press; S. Shettleworth, *Cognition evolution and behaviour.* Oxford University Press. R. A. Brooks. *Flesh and machines: how robots will change us*. Penguin. Last year's biologists recommended a book by Whitby, B.R. (2003), *AI a beginner's guide*, Oxford as a good introduction for neophytes to AI.

(But you are not recommended to buy them). Essential articles, usually one per lecture, and one or two for each seminar are starred and in bold. These should definitely be read. Some of these will be available for purchase as a study pack in Pevensey 3 from Celia Mcinnes (4C18). Others can be downloaded from the web. Some are also available for borrowing from the reserve collection in the Main University Library. The other papers on the reading list shouldn't be ignored, but you aren't expected to read them all! Many of the items are listed to help with essay writing. Single copies of most of these items (apart from books) are available from Dorothy Lamb in the Life Sciences Resource Centre (JMS 3C17), and many can be obtained on-line through the University Library electronic journals. If you have problems getting hold of material or need extra sources, please contact the lecturer concerned.

TIMETABLE

Week	Lecturer	Title	Seminar
1 - Oct 4	AT	Robots & Biology	
2 - Oct 11	AT TC	Robots & Biology Insect navigation	Robot architecture (AT)
3 - Oct 18	TC TC	Insect navigation Path planning	Path integration (TC)
4 - Oct 26	TC RH	Memory and flexible behaviour Motion detection and flow fields in insects	Landmark maps (TC)
5 - Nov 1	RH RH	Motion detection and flow fields in insects 2 & 3	Optic flow (RH)
6 - Nov 8	AT AT	Artificial neural networks 1 and 2	Insight and tool use (TC)
7 - Nov 15	AT DO	Artificial neural networks 3 Concept of number	Artificial neural networks (AT)
8 - Nov 24	DO TC	Concept of number Social organisation of foraging	Categories and concepts (DO)
9 - Nov 29	TC TC	Social learning Social intelligence	Social intelligence (TC)
10 - Dec 8			Workshop

COURSE SYNOPSIS

1. Thinking about Intelligent Behaviour.

Intelligence, adaptive behaviour, adaptation. Some key historical frameworks(with special attention to vision): Cartesianism, Evolution, Cybernetics and dynamical systems theory, `classical' AI, connectionism, Behaviour-based,`Artificial Life.' Relationship between anatomy and function; functional localisation. Interface between biology and engineering. How much do we currently understand all this?

Reading:
(Available on the web: http://www.ai.mit.edu/people/brooks/papers.html)
Extracts from *Brooks, R.A. (1995)."Intelligence Without Reason". In Steels, L. and Brooks, R. (eds.) The Artificial Life Route to Artificial Intelligence: Building embodied, situated agents, 25-81, Lawrence Erlbaum Associates.
Arkin R.C. (1998) Behavior-based robotics. MIT Press.
Boden, M. (ed) (1996) The philosophy of artificial life. Oxford University Press

Braitenberg, V. (1984). "Vehicles: Experiments in Synthetic Psychology", MIT Press. Library: QU 4588 Bra (1 copy in MAIN).
Ashby, W.R. (1960). "Design for a brain: the origin of adaptive behaviour", Chapman. Library: QE 230 Ash (1 copy in RESERVE).
Gibson, J.J. (1979). "The ecological approach to visual perception", Houghton Mifflin. Library: QZ 314 Gib (1 copy in RESERVE, 3 in SHORT).
Gray Walter: see http://www.epub.org.br/cm/n09/historia/turtles_i.htm (follow links)
Proceedings of the four "Simulation of Adaptive Behaviour (SAB): From animals to animats" conferences. Library: QZ 1250 Fro (Several copies in MAIN and RESERVE).

2. Designing Intelligent Behaviour

Special focus on Brooks' approach. Reactive and non-reactive control. Situatedness, embodiment and emergence; behaviour-based robotics; the subsumption architecture. Top-down vs. bottom-up design; hierarchical control structures. General purpose vs. niche-specific; Horswill's `habitatconstrained' vision. The battles: Pros and cons of information processing and internal representation perspectives. Robots and simulations as models of nature.

Reading :
***Webb, B. (1996). "A Cricket Robot". Scientific American, December 1996, 62-67.**
Franceschini, N., Pichon, J.M., and Blanes, C. (1997). "Bionics of Visuo-motor Control". In: Evolutionary Robotics: From intelligent robots to artificial life (ER'97), Gomi, T. (ed.), 49-67, AAI Books.
Deneubourg, J.L., et al. (1991). "The dynamics of collective sorting: Robot-like ants and ant-like robots". In Meyer, J-A., and Wilson, S.W. (eds.), Proc 1st Int. Conf. on Simulation of Adaptive Behaviour: From Animals to Animats, 356-363, MIT Press.

3. Navigation in Insects

Ants and bees are impressive navigators. They leave their nest to collect food from sites that may be located hundreds (ants) or thousands (bees) of metres away. They then return accurately to their nest. To do this, they have at their disposal a repertoire of navigational strategies that must be properly co-ordinated. A primary one is path integration or dead reckoning. Unavoidable inaccuracies arising from path integration are reduced by the insects' use of visual landmarks to specify stereotyped routes. The study of navigation can tell us much about sensori-motor control and 'situated cognition' in these animals.

Reading:
***Wehner, R. Michel, B., Antonsen, P. (1996). Visual navigation in insects: coupling of egocentric and geocentric information. J exp Biol 199, 129-140.**
Wehner, R. (1992) The arthropods. In Animal Homing (ea. F. Papi). pp. 45-144. Chapman and Hall.
Wehner, R. and Srinivasan M. V. (1981) Searching behaviour of desert ants, genus Cataglyphis (Formicidae, Hymenoptera). J. comp. Physiol A, 142:315-338.
Journal of Experimental Biology, Symposium volume on Navigation. Jan 1996 vol 199. (Downloadable from the web: www.biologists.com)
(articles by Srinivasan, M.V. et al., Esch, H & Burns, J.E)
Srinivasan MV, Zhang SW, Bidwell NJ: Visually mediated odometry in honeybees navigation en route to the goal: visual flight control and odometry. *J exp Biol* 1997 **200**:2513-2522.
Srinivasan MV, Zhang SW, Altwein M Tautz J (2000), Honeybee navigation: nature and calibration of the 'odometer'. Science 287, 851 - 853.
Ronacher, B., Gallizi, R., Wohlgemuth, S., Wehner, R. (2000). Lateral optic flow does not influence distance estimation in the desert ant. J. exp. Biol. 203, 1113-1121.

Wohlgemuth S, Ronacher B, Wehner R (2001) Ant odometry in the third dimension. Nature 141, 795-798.

4. Defining Places by Landmarks

Bees and ants use landmarks to specify a place. What kinds of representations of landmarks do these insects have, how do they acquire these representations and how do they use them for navigation? Answers to these questions show how apparently complex tasks can be accomplished in relatively simple ways and mimicked by model navigational systems simulated through artificial evolution.

Reading:

***Collett, T.S. (1992) Landmark learning and guidance in insects. Phil. Trans R. Soc. B 337:295-303.**

Journal of Experimental Biology, Symposium volume on Navigation. Jan 1996 vol 199
(Downloadable from the web: www.biologists.com)
(especially articles by Menzel, R. et al, Zeil J. et al, Lehrer, M., and Dyer, F.C.)

Dale, K., Collett, T.S. (2001) Using artificial evolution and selection to model insect navigation. Current Biology 11, 1305-1316.

Collett, T.S., Collett, M. (2002) Memory use in insect visual navigation. Nature Reviews Neuroscience 3, 545-552.

5. Path Planning by Spiders and Frogs

Many animals must plan efficient routes through cluttered environments and the methods that they use give insights into what they 'know' about their 3-D environment and how this knowledge is used in intelligent planning. We will see the very different strategies and mechanisms adopted by spiders planning routes through complex 3-D mazes and frogs and toads planning detours round barriers, and how planning strategies can be implemented neurally in simple structures.

Reading:

***Arbib, M. A. and Liaw, J.-S. (1995). Sensorimotor transformations in the worlds of frogs and robots. Artificial Intelligence 72:53-79.**

Jackson, R. R. (1985) A web-building jumping spider. Scientific American 253 (Sept):106-113.

Hill, D.E. (1979) Orientation by jumping spiders of the genus Phiddipus during the pursuit of prey. Behav. Ecol. Sociobiol. 5:301-322.

Tarsitano, M.S., Jackson, R.R. (1997) Araneophagic jumping spiders discriminate between detour routes that do and do not lead to prey. Anim. Behav. 53: 257-266.

Tarsitano, M.S., Andrew, R. (1999) Scanning and route selection in the jumping spider Portia labiata. Anim. Behav. 58, 255-265.

Collett, T.S. (1982) Do toads plan routes? J. comp Physiol. 146:261-271.

Menzel E.W. (1973) Chimpanzee spatial memory organisation. Science 182:943-945.

6. Memory organisation: procedural, contextual and episodic

Most intelligent behaviour relies on remembering and utilising previous experiences, both in the short term (working memory) and in the longer term. The importance of long-term memory in allowing flexible behaviour is already seen in insects. We will first consider the use of spatial and temporal context in helping bees and ants retrieve appropriate navigational memories. Vertebrates have more elaborate memory mechanisms. Psychologists divide long-term memories into two very different functional classes: procedural (skills and habits) and episodic (memory of individual events). Until recently it was believed that episodic memory is restricted to humans. However, detailed study of the memory requirements of caching behaviour in birds reveals that birds also have the ability to remember and utilise information about specific events, and similar studies show that rats do too.

Reading:

*__Griffiths, H, Dickinson, A. Clayton, N. (1999) Episodic memory: what animals can remember about their past. Trends in Cognitive Science 3, 74-80.__
Clayton, N.S., Yu, K. S., Dickinson, A. (2003). Interacting cache memories: evidence for flexible memory use by western scrub jays (*Aphelcoma californica*). J. exp. Psychol. Anim. Behav. Processes 29, 14-22.
Clayton, N.S., Dickinson A. (1998) Episodic-like memory during cache recovery by scrub jays. Nature 395, 272-274.
Clayton, N.S., Dickinson A. (1999) Memory for the content of caches by scrub jays (*Aphelocoma coeruslescens*). . J. exp. Psychol. Anim. Behav. Processes 25, 82-91.
Emery, N.J., Clayton, N.S. (2001). Effect of experience and social context on prosective caching strategies by scrub jays. Nature 414, 443-446.
Suddendorf, T, Busby, J. (2003) Mental time travel in animals. Trends in Cog Sci. 7 (9), 391-396.
Squire, L.R. & Kandel E.R. (1999) Memory: from mind to molecule. Scientific American Library.
Sympoium on episodic memory in Philosophical Transactions of the Royal Society 2001, vol 356, pp 1341-1515.
Hampton, R.R. and Schwartz, B.L.(2004). Episodic memory in non-humans: what and where is when? Current Opinion in Neurobiol 14, 192-197.
Ergorul, C. and Eichenbaum, H. (2004) The hippocampus and memory for "What," "Where," and "When". Learning and Memory 11: 397-405.

7. - 9. Visual Coding and Motion Detection in Flies. Neural Pathways, Behaviour, and Algorithms. (3 lectures)

A fundamental question motivating comparisons between animal and machine intelligence is: Could we in principle we make a machine the exactly mimics a human or animal brain? The middle of this century saw developments in universal computing machines implementing simple logical operations and neurophysiology of synapses – the low-level end of the machine vs. organism comparison. Workers such as the mathematician A. Turing and the biologist/philosopher W. McCulloch asked whether the logical operations required for a universal computer could be implemented by a brain, and whether there is more to brains than formal logic. This approach to neural computation is illustrated by work on visual motion, which asks how single synapses in 'special purpose' neural circuitry solve a specific computational problem. Later AMI deals with neural networks which make more general comparisons between machine and brain computational architectures.

Specifically these lectures concern neural mechanisms beneath the insect's eye. For example, Visual motion flowfields are derived from retinal stimuli by integrating from local directional motion signals and are used to stabilise flight. The way local motion signals are abstracted and how they are integrated into behaviour have been a test-bed for ideas at the interface of neurobiology, behaviour, formal modelling and machine vision. We go on to look at how bees and other insects use visual motion signals to control direct level flight, and also manoeuvres such as obstacle avoidance landing, and (in some cases) how these controls are implemented by the nervous system, and have been implemented by designers of autonomous robots.

***Franceschini, N., Pichon, J. M. and Blanes, C. (1992) From insect vision to robot vision. Phil. Trans. R. Soc. Lond. B. 337:283-293.**
***Egelhaaf, M. and Borst, A. (1993) Motion computation and visual orientation in flies. Comp. Biochem. Physiol., 104A:659-473**
***Rind FC, Simmons PJ (1999) Seeing what is coming: building collision-sensitive neurones *Trends Neurosci* 22 215-220:** a brief review of neural mechanisms for detecting (and avoiding) collisions.

Clifford, C. W. G. and Ibbotson, M. R. (2003), "Fundamental mechanisms of visual motion detection: models, cells and functions", Progress in Neurobiology, 68, 409-437: An excellent but lengthy review describing the fundamental properties of motion detecting algorithms and what we know about the corresponding neural circuitry vertebrates and invertebrates

Krapp, H. G. and Hengstenberg, R. (1996), "Estimation of self-motion by optic flow processing in single visual interneurons", Nature, 384, 463-466: An elegant paper describing an impressive match between optic flow fields and the response properties of cells in the fly's visual system.

Poggio, T. and Koch, C. (1987) Synapses that compute motion. Scientific American, May 1987, pp.42-48: an easy read about synaptic mechanisms that could provide the non-linear properties needed for motion detection.

10 to 12. Artificial Neural Nets (ANNs)

10. Basics and History
What ANNs are. Feedforward and recurrent nets. Learning vs. hardwired. The Perceptron; training, testing and generalisation. Weight vectors and error surfaces; gradient-descent learning. The need for a hidden layer. NETtalk asan example. What ANNs are good for.

11. Some details of learning mechanisms.
Backpropagation. Kohonen's self-organising maps. Reinforcement learning (Barto's pole balancer).

Reading for 10 and 11:
***Elman, J.L. et al. (1996) Rethinking Innateness. MIT Press. chap 2: Why connectionism? Pp 47-106.**
Sejnowski, T.J. and Rosenberg, C.R. (1986). "NETtalk: a parallel network that learns to read aloud". Reprinted in the book below, Chapter 40
Anderson, J.A. and Rosenfeld, E. (eds) (1988). "Neurocomputing: foundations of research", MIT Press. Library: QU 4550 Neu (1 copy in MAIN, 1 in SHORT).
McCord Nelson, M. and Illingworth, W.T. (1991). "A Practical Guide to Neural Nets", Addison-Wesley. Library: QZ1335Nel, (1 copy MAIN, 1 SHORT).

Browse the QZ 1335 section in the library.

12. ANNs and nature.

What's the relation between ANNs and brain function, anatomy and psychology? "Biological Plausibility" of architectures and learning regimes. Hebbian learning. Local and distributed representations in ANNs. Graceful degradation. Symbolic vs. non-symbolic, semantic grounding. Computational Neuroethology, ANNs as "artificial nervous systems"; time and dynamics. Artificial evolution of ANN designs.

Reading:
(Available on the web: http://citeseer.nj.nec.com/cliff91computational.html)

***Cliff, D. (1991). "Computational Neuroethology: A Provisional Manifesto". In Meyer, J-A., and Wilson, S.W. (eds.), Proc 1st Int. Conf. on Simulation of Adaptive Behaviour: From Animals to Animats, 29-39, MIT Press.**

Beale, R. and Jackson, T. (1990). "Neural Computing - an introduction", chapter "Kohonen Self-Organising Networks", IOP Publishing.
Roitblat, H.L. et al. (1991). "Biomimetic Sonar Processing: From dolphin echolocation to artificial neural networks." In Meyer, J-A., and Wilson, S.W. (eds.), Proc 1st Int. Conf. on Simulation of Adaptive Behaviour: From Animals to Animats, 66-76, MIT Press.

13 to 14. The concept of number in man and animals

Skills such as navigation or language are clearly of direct benefit to animals. By comparison mathematics is a triumph of human intellect, whose selective advantages, origins and corollaries in other species are less obvious. Our objective is to set this achievement in a biological context: what might have been the evolutionary antecedents of human mathematics, and what is its neural basis? The main subjects are: i) evidence that adult humans handle numbers as analogue quantities - contrary to the common intuition that integers are discrete 'cognitive' entities . ii) evidence for numerical skills - or their lack - in non-human primates and other animals. iii) findings on the neurophysiological mechanisms that monkeys use for handling number.

Reading:
***Feigenson, L., Dehaene S. and Spelke, E. (2004). Core systems of number. Trends in Cog. Sci. 8, 307-314.**

***Nieder, A., Freedman, D.J., and Miller, E.K. (2002). Representation of the quantity of visual items in the primate prefrontal cortex. *Science*. 297:1708-1711.**

Background reading

S. Dehaene, The Number Sense: How the Mind Creates Mathematics. Oxford, 1997 (also available in a Penguin edition).

Dehaene, S, Molko, N., Cohen, L. and Wilson A.J. (2004). Arithmetic and the brain. Current Opinion in Neurobiology, 14 218-224.

Hauser MD (2000) What do animals think about numbers? American Scientist Vol. 88,144-151

15. The Social Organisation of Honeybee Foraging
The socially organised behaviour of a hive of honey bees during foraging is a wonderful example of how simple rules followed by individual bees leads to exquisitely organised and effective global behaviour without centralised control. Those working in this field like to consider individual bees as individual neurones and a hive of bees as a brain. We will mostly emphasise how information concerning the availability and need for nectar is transferred within the hive, and how good decision making can arise despite the limited knowledge available to individual bees.

Reading:
***Seeley, T.D., Towne, W.F. (1991) Collective decision making in honey bees: how colonies choose among nectar sources. Behav. Ecol. Sociobiol. 28:277-290.**
Seeley, T.D. (1992) Tactics of dance choice in honey bees: do foragers compare dances. Behav. Ecol. Sociobiol. 30:59-69.

Michelsen, A., et al. (1992) How honeybees perceive communication dances, studied by means of a mechanical model. Behav. Ecol. Sociobiol. 130:143-150.
Seeley, T.D. (1994) Honey bee foragers as sensory units of their colonies Behav. Ecol. Sociobiol. 34:51-62.
Seeley, T.D. (1995) The Wisdom of the hive: the social physiology of honey bee colonies. Harvard University Press.
Seeley, T.D. (1999) Group decision making in swarms of honeybees. Behav. Ecol Sociobiol. 45, 19-31.
H. Esch, S.W. Zhang, M.V. Srinivasan & J. Tautz (2001): Honeybee dances communicate distances measured by optic flow. Nature (Lond) 411, 581-583.
Seeley, T.D., Buhrman S.C. (2001) Nest-site selection in honey bees: how well do swarms implement the best-of-N decision rule? Behav. Ecol. Sociobiol. , 416-427.
Scott Camazine (ed) (2001*) Self-Organization in Biological Systems* Princeton UP

16. Observational learning and culture

Observational learning speeds up the acquisition of environmental affordances and skills. Even in the absence of language, it allows information and skills to be transmitted between individuals and, over time, between generations. We will consider examples of observational learning in humans and other animals, possible neural mechanisms underlying imitative learning, and elements of culture in animals.

Reading:

*** Boesch, C. (1996) The emergence of culture among wild chimpanzees. Proc. Brit.Acad 88, 251-268.**
Multi-authored feature article in Science 1999 vol 284, 2070-2076. Chimps in the wild show stirrings of culture.
McGrew, W.C. (1998) Culture in non-human primates. Ann. Rev. Anthropol 27, 301-328.
Wolpert, D.M., Doya, K., Kawato, M. (2003). A unifying framework for motor control and social interaction. Phil. Trans. R. Soc. Lond. 358, 593-602.
Whiten, A (1998) Imitation of the sequential structure of actions by chimpanzees (Pan troglodytes). J. comp. Psychol. 112, 270-271.
Meltzoff, A.N., Decety, J. (2003). What imitation tells us about social cognition. Phil. Trans. R. Soc. Lond. 358, 491-500.
Byrne, R.W. (2002) Imitation of novel complex actions: what does the evidence from animals mean. Advances in the study of behavior 31, 77-105.
Heyes, C. (2001). Causes and consequences of imitation.Trends in Cogn. Sci.2001 5:6:253-261
Rizzolatti, G., Luppino, G. (2001). The Cortical Motor System. Neuron 31:6:889-901.
Gallese,V, Christian Keysers, C and Rizzolatti, G. (2004). A unifying view of the basis of social cognition. Trends in Cogn. Sci. 8, 369-403

17. Social Intelligence and 'mind reading'

To be socially skilled, one needs to anticipate the behaviour of others. Prediction might be easier if an animal can guess what another animal is thinking or intending and there have been explicit suggestions that apes are 'mind-readers'. How can this be investigated experimentally? Empirical studies in humans have explored whether infants are aware that others can have false beliefs. In non-human primates and some other mammals, experimental studies have been concerned with whether an animal understands what another animal is looking at.

Reading:

***Frith, U and Frith, C.D. (2003). Development and neurophysiology of mentalizing. Phil. Trans. R. Soc. Lond. 358, 459-473.**

Byrne, R.B. (1995) The thinking ape. Oxford University Press.
Hare, B., Call., J, Tomasello, M (2001). Do chimpanzees know what conspecifics know? *Anim. Behav. 61*, 139-151.

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Miklósi, A.,Kubinyi, E Topal, J., Gácsi, M., Virányi, Z., Csányi, V. (2003). A simple reason for a big difference: wolves do not look back at humans, but dogs do. Current Biol. 13, 763-766.

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UNDERGRADUATE SEMINARS

1. Does behaviour-based robotics scale up?

Reading:
(Available on the web: http://icl-server.ucsd.edu/~kirsh/Articles/Earwig/earwig-cleaned.html)
***Kirsh, D., 1991. "Today the earwig, tomorrow man?" Artificial Intelligence 47, pp161-184 (Reprinted in Boden's "Philosophy of Artificial Life"). Additional reading on this: **Brooks "From Earwigs to Humans"**
On the web: http://www.ai.mit.edu/people/brooks/papers.html

We'll divide into two groups, one arguing Kirsh's case and the other that of Brooks. Reading as much as possible before the seminar of Kirsh's paper, and the Brooks reading for Lecture 1, will help a lot. Here's just some of the things to think about while reading Kirsh:

* Are there bits you don't understand? (Lecturer will explain)
* Does Kirsh's statement of Brooks' case square with your reading of him?
* Is it right to drive a wedge between the sense-driven and the representation-driven, and expect to be able to make a hybrid having elements of each?
* How much does Kirsh's argument appeal to intuition and introspection?
* Some of Kirsh seems to assume a strong division between the mechanisms of perception, reasoning, action, etc, but does he mean this and does it matter?
* What can Kirsh mean by "computational cost"?
* One of Kirsh's strongest points is to do with learning. What would Brooks say?
* Who's right?

Don't be frightened by this difficult argument - we'll do it in a fun way.

2. Path integration

Reading (in study pack) *Zeil, J., Layne, J (2002) Path integration in fiddler crabs and its relation to habitat and social life. In (Wiese, K. ed) Crustacean experimental systems in neurobiology. Springer Verlag: Berlin.

Path integration (PI) is used by many animals in a variety of intriguing ways. Fiddler crabs are particularly reliant on PI, as the Zeil and Layne review make clear. The aim of this tutorial is to make sure you are clear about the basics of PI, its use in navigation and then to explore the way that it is integrated into the behaviour of fiddler crabs.

1. What is path integration and how has it been demonstrated?
2. Why is path integration useful for learning routes?

3. What is the evidence that insects store the PI coordinates of significant places and can then navigate to those places using PI? How do crabs exhibit the same ability?
4. What relationships might there be between landmark navigation and PI? Why might it be useful for familiar landmarks to be labelled with PI coordinates and how might one test whether PI coordinates are attached to landmarks?
5. How are fiddler crabs thought to measure distance and direction?
6. What is the evidence that crabs have a continuous readout of the state of their path integrator.
7. How might the crabs integrate information from retinal elevation and path integration in order to measure the distance of an intruder from their (often invisible) burrow entrance?

3. Integration of spatial maps

Reading (in study pack) * A.P.Blaisdell and R.G.Cook (2004). Integration of spatial maps in pigeons. Animal Cognition. In press.

This paper approaches the vexed question of 'cognitive maps'. Such maps are usually held to be an encoding of spatial information in Earth-based coordinates that can be used to plan novel routes. As the authors explain, it has proved difficult in the past to demonstrate the existence of such maps through behavioural experiments. The authors argue that their current experiment does so. In the tutorial we will discuss the concept of cognitive maps, how they might be realised and how used. And we'll see whether we are convinced that the experiment in the paper does what the authors hope. Here are some questions to think about while reading the paper.

1. Navigational maps can be of different kinds – route, topological, metric. Consider how they might be implemented and their various benefits and drawbacks.
2. How does the experiment in the paper aim to establish the existence of a cognitive map?
3. Why do the authors introduce their experiment by discussing the learning of temporal sequences?
4. What kind of detailed representation or encoding of spatial information do you think the authors suppose the birds to construct?
5. How might the birds use the spatial information in their encoding to navigate to a goal?
6. Might there be simpler explanations of the birds' behaviour in this experiment that do not involve cognitive maps (in the sense defined above)?
7. The basic design of the experiment seems nice. How could it be improved?
8. One problem is building a cognitive map is how an animal adds to it while exploring its environment. How do the authors suppose that their pigeons build up a map?

4. A simple algorithm to guide the landing of bees

***Srinivasan MV et al. (2001) Landing strategies in honeybees, and possible applications to autonomous airborne vehicles. *Biol Bull.* 200, 216-221.**

Careful studies of insect behaviour often suggest new algorithms for robotic control. This paper reviews some recent findings on the way honeybees land on the ground. The authors find that bees use a surprisingly simple algorithm that connects flight speed, image speed and altitude. The paper also describes how the algorithm is implemented to control a robotic gantry.

Issues to think about for discussion:
1. What basic properties should a 'good' landing algorithm have?
2. What can we infer about the internal structure of the honeybee's flight control system by studying how it lands?
3. Is the robotic implementation of the algorithm a good description of the processes that the honeybee performs during landing?
4. Which aspects of the robotic implementation are biologically implausible?
5. In what situations might the bee's landing strategy fail?
6. What modifications (if any) would you want to be made to the landing algorithm before it was used in a real aircraft?

5. Tool use and insight

Readings (in study pack):
***Heinrich B (1995) An experimental investigation of insight in common ravens. The Auk 112:994-1003.**
***Weir, A.S., Chappell, J. & Kacelnik A. (2002). Shaping of hooks in new caledonian crows. Science 297, 981.**
***Visalberghi, E., Limongelli, L. (1994) Lack of comprehension in tool-using capuchin monkeys. J. comp. Psychol 108: 15-22.**

(For more on cognition in birds see two recent books: B. Heinrich. The Mind of the Raven; I Pepperberg. The Alex Studies, Harvard U.P.)

How do animals solve problems using tools? Do they reach solutions by trial and error, or do they have insight into what they are doing? How can one get animals without language skills provide answers to such questions? In this tutorial, we will look at one study on Capuchin monkeys. The authors conclude that although these monkeys are very adept at using tools in artificial tasks, they do not understand what they are doing. A second study on ravens and a third on crows reach exactly the opposite conclusion.

1. What do you understand by insight? Why is it so difficult to demonstrate either its presence or its absence? How might one exclude the possibility that apparently insightful behaviour is a consequence of learning or of innate predispositions? Is the latter a sensible question?
2. What evidence have Visalberghi et al. given to show that Capuchin monkeys don't have insight into the tube task? Does it convince?
3. What does the string task require ravens to do?
4. How do crossed strings increase its difficulty?
5. What does the sheep's head test show?
6. Summarise Heinrich's evidence for insight in ravens.
7. Does the presence of large individual differences in behaviour affect his argument?
8. Could this apparently insightful behaviour tap into some innate part of the bird's normal feeding behaviour?
9. What 'naïve physics' does the bending of wire into hooks imply – again could this ability be based on behaviour patterns that crows normally exhibit?

6. Artificial Evolution, neural nets, and robotics
Reading:
"Artificial Evolution: A new path for Artificial Intelligence?" P. Husbands, I. Harvey, D. Cliff, G. Miller Brain and Cognition Vol. 34, No. 1, pp130-159

Just extracts: pages 1-17 and 24-27. Files are available to download at: http://www.cogs.susx.ac.uk/users/adrianth/TEACHING/AMI/SEMINAR/

Ask a friend if you have problems printing. Don't be put off if there are parts of the paper that you can't understand: just make a note to raise that at the seminar and skip them.

To think about:

1. How is this "artificial evolution" similar to natural evolution, and to the human breeding of animals and plants, and how is it different?
2. How does the design of an ANN though artificial evolution compare to the other ANN `learning' methods?
3. Why were the authors able to depart from a standard regular ANN structure, such as a feedforward layered network, and why did they think this was worthwhile?
4. The paper is inspired by nature, but could such work give anything back to biologists?
5. How does this compare to Brooks' approaches?
6. What to you think might be achievable, and unachievable, using such methods? Are these conclusions affected by exactly what sorts of evolutionary algorithms and neural networks are chosen?

7. Concepts and categories

Reading (in study pack) *Cerella J (1979) Visual classes and natural categories in the pigeon. J. Exp. Psychol.: Human Perception and Psychology. 5, 68-77

Questions about Cerella's article:

1. What is the difference between Locke's 'traditional' notion of a category, and the more modern view proposed by Rosch? What are the implications of this difference for the process of categorisation.
2. Explain the experimental procedure used by Cerella to test pigeons.
3. Explain the main conclusion of experiment 1.
4. How is this elaborated by experiments 2 and 5.
5. Compare the ways humans and pigeons categorise stimuli. How might humans do things differently, and how might this idea be tested experimentally.
5. How might one test hypotheses about category formation using a computer model.

8. Reading (in study pack): Bshary, R., Wickler, W., Fricke, H. (2002). Fish cognition: a primate's eye view. Anim. Cognition 5, 1-13. And paper by U. and C. Frith (2003) Development and neurophysiology of mentalising (lecture 17).

The first paper argues that many of the terms used to label complex cognitive skills in primates can be applied appropriately to fish behaviour, and poses the question: How are we to distinguish between levels of smartness in fish and primates. We'll try to tackle this question by considering among other things

1. The selection pressures that might have led to larger brains and complex cognition. Why, for instance, are the problems of social interaction suggested to be more powerful drivers towards complex cognition than are problems presented by the physical environment (e.g., foraging)?
2. Do primates perform similar tasks to fish but in very different ways (e.g., understand to some degree the intentions and motivations of social partners, theory of mind)?
3. Specialist vs. generalist intelligence.

Sample Essay Titles

1. We can build machines (computer programs) to play chess more successfully than we can devise a two-legged robot to walk without falling over. What implications does this have for those trying to build intelligent machines? The chess-playing program works by having perfect knowledge of the chess-board and applying a chain of abstract reasoning to work out the best thing to do next, searching methodically through millions of possibilities. How does this compare with the way animals behave adaptively in the real world?

2. Attempts to understand nervous systems, and the way in which animals (and hopefully robots) behave adaptively or `intelligently', have a long history of being wrong (many now think). How confident can we be that our current
thinking represents progress? Why? Part of the current approach is to study "simple" animals like insects. How might this be able to shed light on more complex animals like humans, or are we now simply evading the difficult questions?

3. Discuss the strategies that insects use in their navigation and how they might be implemented on a machine. What features would be particularly easy or particularly difficult to implement and why?

4. Outline what is meant by the term elementary motion detector (emd). How might emd's be implemented in nervous system or flies or other animals, and how might the principles they embody be relevant to the design of autonomous vehicles, and artificial intelligence in general?

5. A wealthy agency (the US airforce perhaps) requests your advice on whether they should invest in implementing principles derived from the study of insect flight control for the design of autonomous agents. Make a case outlining general principles, giving examples of work done so far, and reaching a clear conclusion.

6. To what extent does the organisation of real nervous systems exemplify Brooks' subsumption architecture?

7. Discuss the advantages and disadvantages of the approach of intelligence as adaptive behaviour, contrasting that approach with knowledge-based AI.

8. Are recent developments in visual guidance of autonomous agents an improvement on traditional approaches to problems of path planning, or a seductive dead-end?

9. Is it useful to compare the function of neural synapses with the logical operators used in computing? Illustrate your answer with examples of neural mechanisms.

10. Are neural networks useful as metaphors or models for understanding brains? Illustrate your answer with examples from work on signal evolution and/or pole-balancing.

11. Discuss F. Crick's assertion: 'The brain isn't even a little bit like a computer'

12. Why are primate brains big?

13. Why might an artificial neural network model of behaviour-generation be of more interest to biologists than, say, a computer program having a set of rules that generates roughly the same behaviour? Hint: discuss applying constraints of biological plausibility, investigating failure modes, etc.

14. How might the potential for learning within an artificial neural network model be useful when investigating biological phenomena (eg. by using situated robotics)? What might be the uses of the various training regimes, learning rules, and network architectures, in this context?

15. I have a feed-forward neural network with one hidden layer. I train it using the back-propagation rule so that it can control a robot to avoid obstacles. The network has four inputs, which represent when an obstacle is detected in front, behind, or to the left or right of the robot. The outputs tell the robot whether to turn 90-degrees left or right, or whether to go exactly 10.0 cm forwards in this particular time-step. Why is analysis of the learnt network unlikely to shed much light on how animals achieve similar behaviours? How else would you criticise this experiment? How might it be improved?

16. ‘The difference in mind between man and higher animals, great as it is, certainly is one of degree and not kind.’ Discuss this claim of Darwin.

17. Distinguish between episodic and procedural memories, and discuss differences between the storage and retrieval of the two kinds. What do you suppose episodic memories are for and how can they be demonstrated in non-human animals?

18. Observational learning/imitation - why is it important and what mechanisms make it work?

19. What is a perceptual category, why might we doubt that (non human) animals can form them? Discuss experiments that test the hypothesis that animals can form categories,

20. Is the difference between human and animal cognition qualitative or quantitative? Answer with reference numerical skills and 'numerical neurons' in non-human primates, and other relevant studies of animal brains and behaviours.

21. How does global order in the foraging activity of a colony of bees emerge from local information processing by individuals?

22. There are various kinds of artificial neural network `learning', such as supervised (eg. the backpropagation technique), self-organising (eg. Kohonen maps) and reinforcement learning. How do these relate to the learning seen in animals? (You could discuss at the level of neural mechnisms, or of behaviour/psychology, or both. Perhaps you could mention learning in animal-like robots.)